Population Dynamics and Management Optimization of *Rupicapra rupicapra* in Northern Italy

by

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ABSTRACT

Although chamois (Rupicapra rupicapra) is an ungulate much appreciated by hunters in the alpine region, its demography was not well known at least with reference to the Italian populations. The main porpouse of the research work was to build an appropiate model which describes the dynamics of a chamois population and to use it for optimizing the rate of harvesting. Data from 1966 to 1990 collected by Dr. Guido Tosi in Azienda Faunistica di Valbelviso - Barbellino were employed to estimated demographics parmeters. As the data were structured in groups of ages, the mortality pattern along age was determined by fitting different survival functions to these age groups. The existence of density dependence in fecundity and mortality rate was also tested against data. An stochastic demographic model was finally built to investigate and optimize management policies on the chamois population. The optimization produce a Pareto frontier for multiples goals. It is also presented.

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Rupicapra rupicapra in Northern Italy

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Although chamois (Rupicapra rupicapra) is an ungulate much appreciated by hunters in the alpine region, its demography was not well known at least with reference to the italian populations. The main purpose of the research work was to build an appropriate model which describes the dynamics of chamois population and to use it for optimizing the rate of harvesting.

Data from 1966 to 1990 about kid and hunted individual number, and from 1981 and 1990 about total individual number structured in group of ages were used. These data were collected by Guido Tosi in Azienda Faunistica di Varbellino- Balbelviso.

The following steps were followed:

1- To evaluate Density Effect on Population Parameters
2- To estimate Survival Curve including Density Effect
3- To build the Simulation Model
4- To evaluate different Hunting Policies

DENSITY EFFECT ON POPULATION PARAMETERS

In table 1 it is possible see that growth rate and mortality rate (Mortality rate was estimated using two ways an index which was estimated using the carcasses found number, and the number of death animal which was estimated using consecutive census) present significant regression with total density with 2 years of time lags. The natality rate presented no significant regression with density, but presented good fit (P=<0.0001) to the following model independent of density

$$K_t = a * F_t + \epsilon$$

where K_t is kid number at time t
F_t is $\geq$ 2 year-old female number at time t
ϵ is estimation error

Table 1. Level of Significance for Linear Regression model of some population parameters (dependent variable) against density with different time lags

Dependent Variable	Indep. Variable: Density without time lag	Indep. Variable: Density one year lag	Indep. Variable: Density two years lag
Growth rate (General Logistic model)	r= 0.21 P= 0.10	r= 0.52 P= 0.03	r= 0.79 P= 0.01
Natality rate	P= 0.91	P= 0.255	P= 0.07
Mortality rate index			
Total Individual Number	P= 0.24	P= 0.31	P= 0.01
≥ 1 year-old Males	P= 0.12	P= 0.18	P= 0.003
≥ 1 year-old Fem.	P= 0.15	P= 0.13	P= 0.001
Kids	P= 0.12	P= 0.86	P= 0.28
Mortality rate (using consecutive census)			
Total Individual Number	P= 0.07	P= 0.03	P= 0.01
≥ 1 year-old Males	P= 0.13	P= 0.05	P= 0.02
≥ 1 year-old Fem.	P= 0.28	P= 0.37	P= 0.004
Kids	P= 0.41	P= 0.24	P= 0.04

r is correlation coefficient
P is probability level

Although linear model was significant for mortality rate on 2 year delayed density, the Y intercept was negative (Table 2). That means there are positive immigration rate. But it is no possible because it was a closed population. Therefore we probed with an exponential model regression which resulted significative to P = 0.05 (Table 2) (Fig 1).

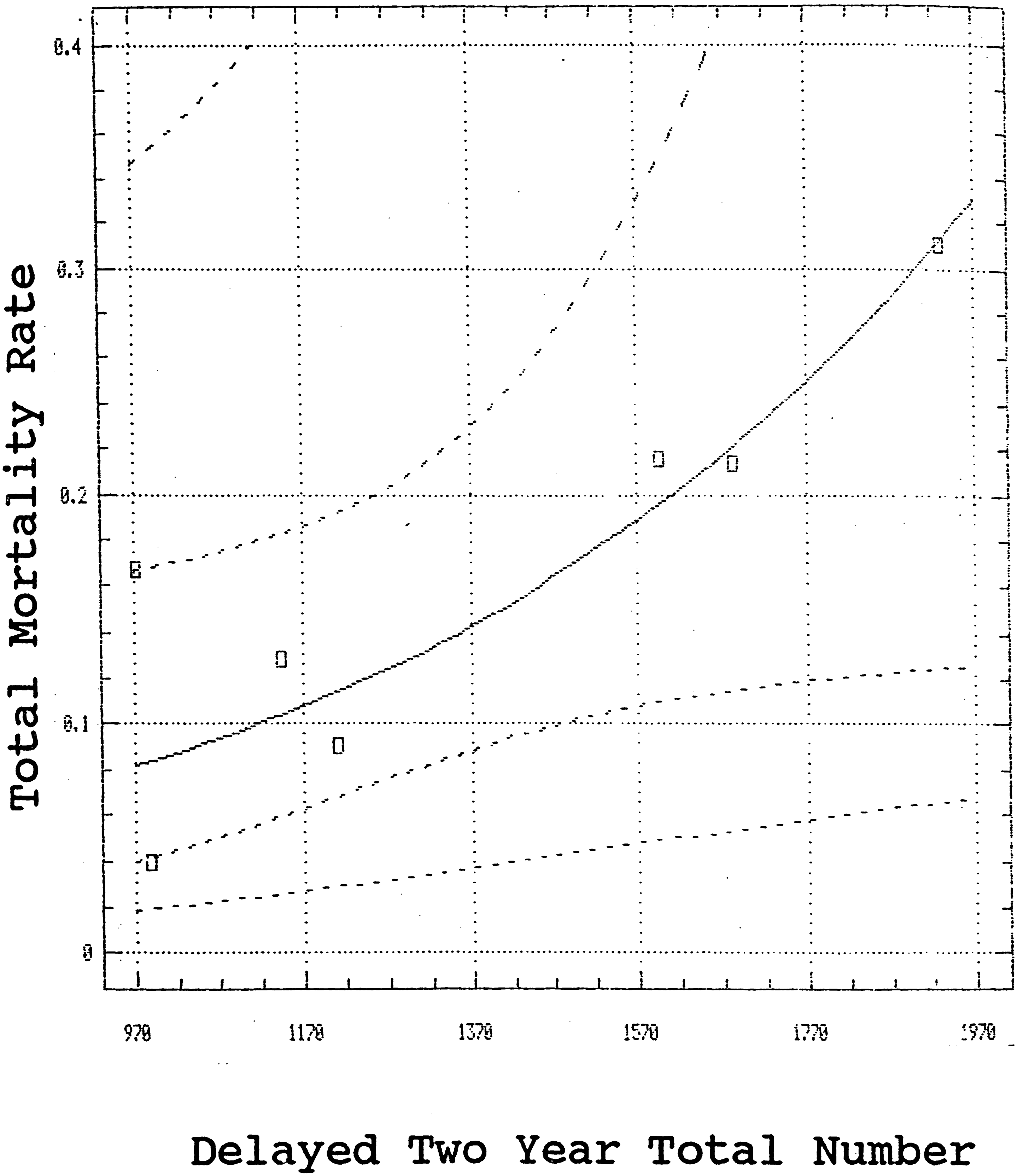
This result could be related with the effect of an epidemic illness, the keroconjuntivitis. This illness usually appears some years after the biggest density.

Table 2. Comparison between Exponential and Linear Regression Model

Population Parameter	Exp. Model P	Exp. Model r	Linear Model P	Linear Model r	Linear Model a
Mortality rate index					
Total Individual Number	0.001	0.94	0.006	0.89	- 7.7
≥ 1 year-old Males	0.003	0.92	0.003	0.96	- 8.1
≥ 1 year-old Fem.	0.004	0.91	0.001	0.99	-10.0
Mortality rate (using consecutive census)					
Total Individual Number	0.04	0.76	0.01	0.86	- 3.8
≥ 1 year-old Males	0.04	0.76	0.02	0.94	- 7.7
≥ 1 year-old Fem.	0.03	0.92	0.004	0.90	-11.5

P is probability level
r is correlation coefficient
a is Y intercept

Fig 1. Exponential Regression between Total Individual Number Mortality Rate and Two Year Delayed Total Individual Number.



While the Kid mortality rate using consecutive census presented good fitted against two years delayed total density, kid mortality index did not present good fit. By other hand the kid mortality rate presented a good fit to a model which includes Allee effect (r^2=0.91) (Fig 2). This effect could be produce by predation of king eagle (<u>Aquila chrysaëtus</u>). The model have the following form:

$$MRK_t = a + b * K_t + c * K_t^2 + d * N_{t-2}$$

where MRK_t is kid mortality rate in t time,
K_t is kid number in t time,
N_{t-2} is total number in t-2 time.

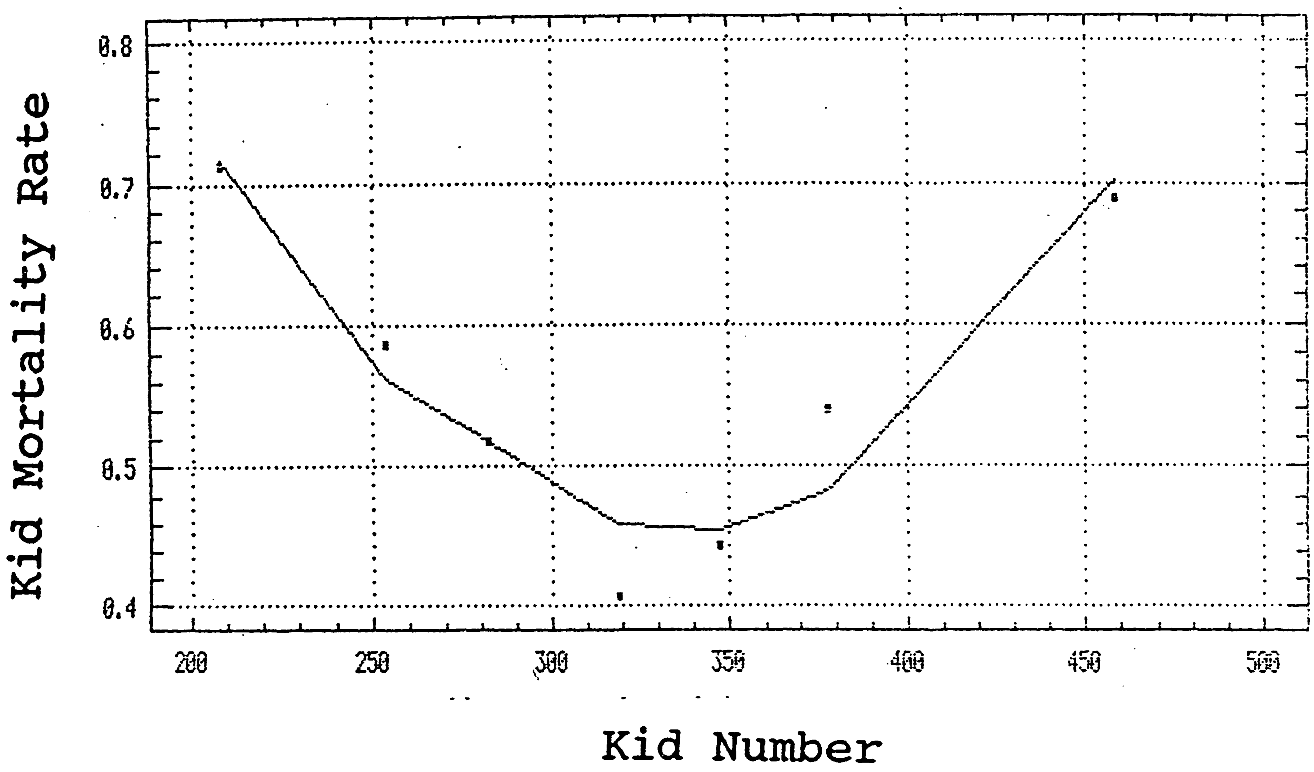


Fig 2. Kid Mortality Rate vs. Kid Number

SURVIVAL CURVE ESTIMATION

Survival curve was estimated to calculate the mortality between ages beginning at age 1. We matched the 9 year age structure data against the result of a simulation model which reproduced the age structure, following different survival curve forms. Three different theoretical survival curve were used (Weibull, Exponential Power and Double Exponential Distributions, Table 3a). As these do not include density effect, we multiplied them by a function G which includes this effect. Function G was deduced from the exponential regression between adult mortality rate and two years delayed density. Function G form is

$$G_t = [1- \exp(a + b*N_{t-2})]/[1-\exp(a)]$$

To parametrize survival curve we minimized sum of squared of difference between field data and simulated model, using Downhill Simplex method.

We estimated confidence interval of parameters using Gallant (1987) suggestion

$$\tilde{\theta}_i \pm t_{0.025} * \sqrt{(s^2 * \tilde{c}_{ii})}$$

where $\tilde{\theta}_i$ is ith estimated parameter,
$t_{0.025}$ is critical value of Student distribution with (n-p) freedom, where n is the number of data and p is the number of parameters,
s^2 is the variance estimator,
$\tilde{c}_{ii}$ is ith element of $\tilde{C}$ matrix diagonal,

$\tilde{C}$ matrix is: $\tilde{C} = [F'(\tilde{\theta}) * F(\tilde{\theta})]^{-1}$ where $F(\theta)$ matrix is the jacobean of function $f(\theta)$ (data vector).

Only Exponential power distribution presented parameters without 0 in their confidence interval (Table 3b)

Tabla 3-a Survival Models Formal

Power Expont. Dist.	$S_t = \exp(1-\exp((t/\alpha)^{\beta}))$
Double P. Exp. Dist.	$S_t = \exp(1-\exp(\exp(\alpha * (t)^{\beta})-1))$
Weibull Distribution	$S_t = \exp(-(t/b)^{c})$

α, β, a, b, c are funtions parameter
S_t is survival from age 1 to t

Tabla 3-b Minimization Results

Female			
Model	CM	Parameters	
Power Exp. Distribution	2228	α= 11.29 ± 3.59	β= 3.69 ± 8.28
Double Exp. Power Dist.	2172	α= 4.12e-18 ± 1.47e-15	β=13.93 ±18.96
Weibull Distribution	2497	b= 10.04 ± 35.58	c=97.23 ± 885.7

Male			
Model	CM	Parameters	
Power Exp. Distribution	1434	α= 6.86 ± 3.46	β= 11.29 ± 7.41
Double Exp. Power Dist.	1427	α= 1.52e-6 ± 1.05e-4	β= 6.65 ± 5.55
Weibull Distribution	1426	b= 6.58 ± 2.52	c= 13.81 ± 8.11

CM is the minimization average square

SIMULATION MODEL

Population dynamics of chamois was described by the following equations:

$K_t = F_t * b + \epsilon$ where K_t is kid number at t time,
F_t is ≥ 2 year-old female number at time t,
b is fecundity rate.

$I_{x(t)} = T_{x-1(t-1)} * I_{x-1(t-1)} + \epsilon$

where $I_{x(t)}$ is number of x age individual at time t,
$T_{x-1(t-1)}$ is survival between x-1 age and x age at t time,

For x=0

$T_x = 1-(2 - 0.01*K_t + 0.00003*K_t^2 + 0.00003*N_{t-2})$,

For x=0

$T_x = Sob^x * G$ where Sob_x was calculated following Power exponential distribution model.

The model was verified using 1981 to 1990 census data (Fig 3). Fig 4 shows a run of 45 years with initial conditions equal a 1983.

Fig 3. Chamois Total individual number from 1981 to 1990 in Azienda di Varbellino Balbelviso. (Census Data --- , Model Result _______).

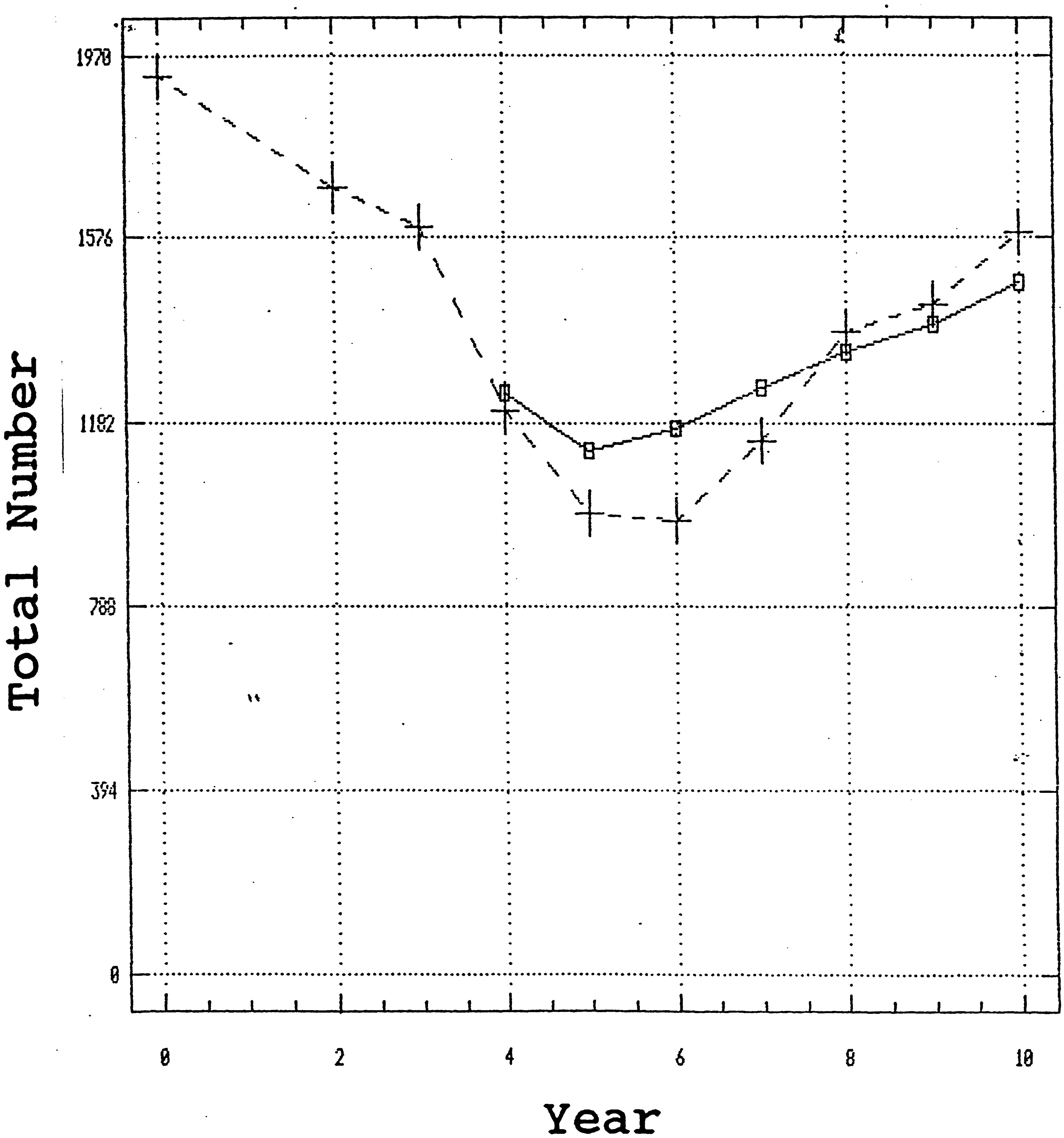
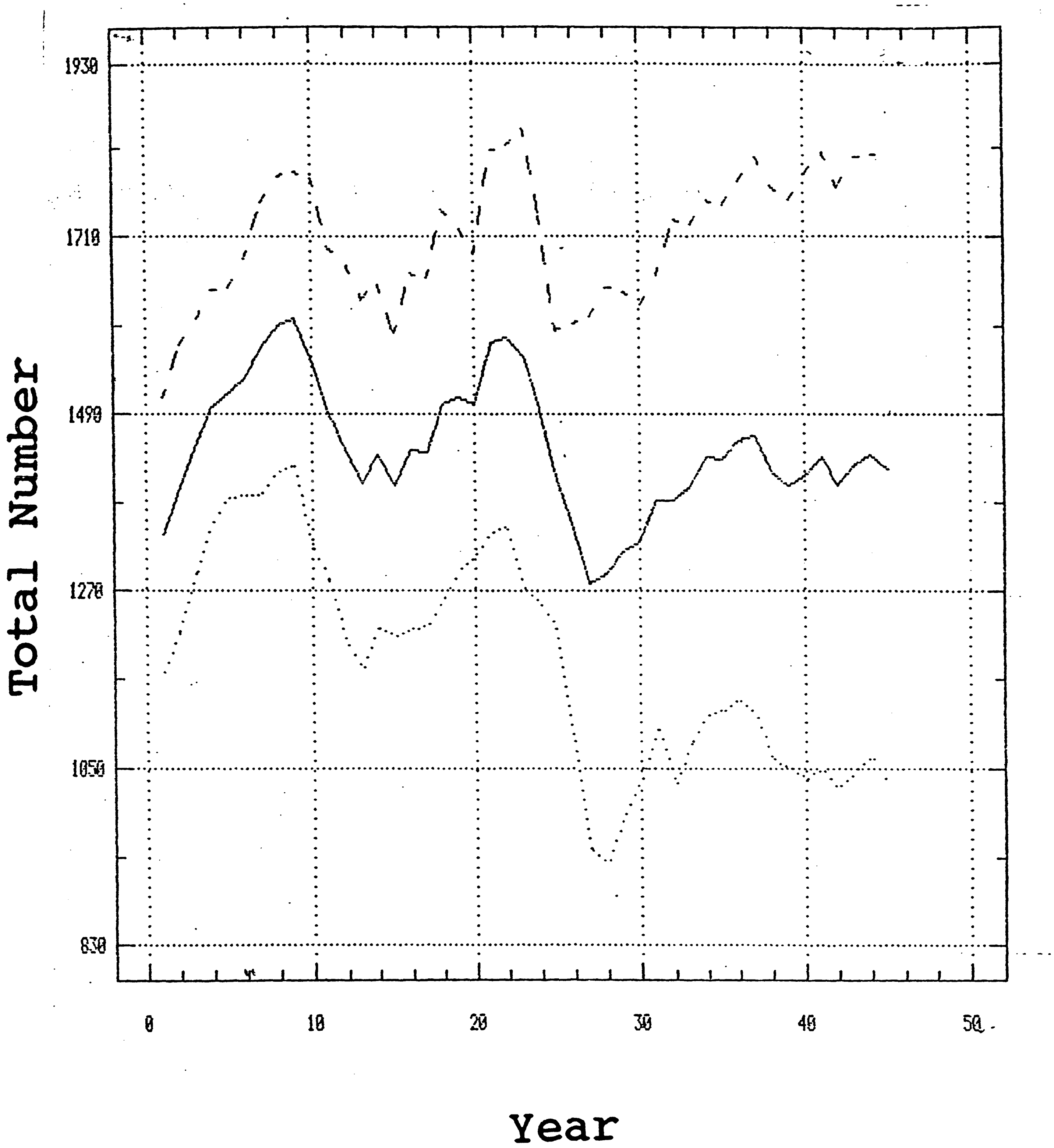


Fig 4. Stocastic model series of Chamois Total Individual Number. (20 runs) (Maximum Value ---, Average _____, Minimum ....).



HUNTING POLICIES

Management purposes were:

a) High number of harvested animals
b) Short variance of number of harvested animals
c) High animal stock after harvesting.

Therefore goal function was

$$\max_{z} \{Q, -V, M\} \quad \text{for } z \in Z, \quad \text{for 20 runs}$$

where Q is hunted animal average of 20 runs,
V is variance of hunted animal average of 20 runs,
M is minimum population value presented in 20 runs,
Z is set of viable policies.

Three different kinds of harvesting policy were tested:
a) Fixed proportion (It harvest a constant proportion of population level, which could be different in each age class)
b) Fixed reproductive stock (It harvest the difference between total adult and an a prefixed adult level)
c) Traditional chamois harvesting (It harvest between 10% to 15% population level, but 50% correspond to between 1 to 3 years old).

In Table 4 and Figs 5, 6 and 7, we present Pareto frontier.
None Traditional policy resulted viable. The fixed reproductive stock policies resulted maximized goals a and c, but fixed proportion optimized goal b.

Fig 5. Viable Policies Distribution on Goals Space (Hunted Animal Average Q, Variance of Hunted Animal Average V, + Paretto Frontier Policy).

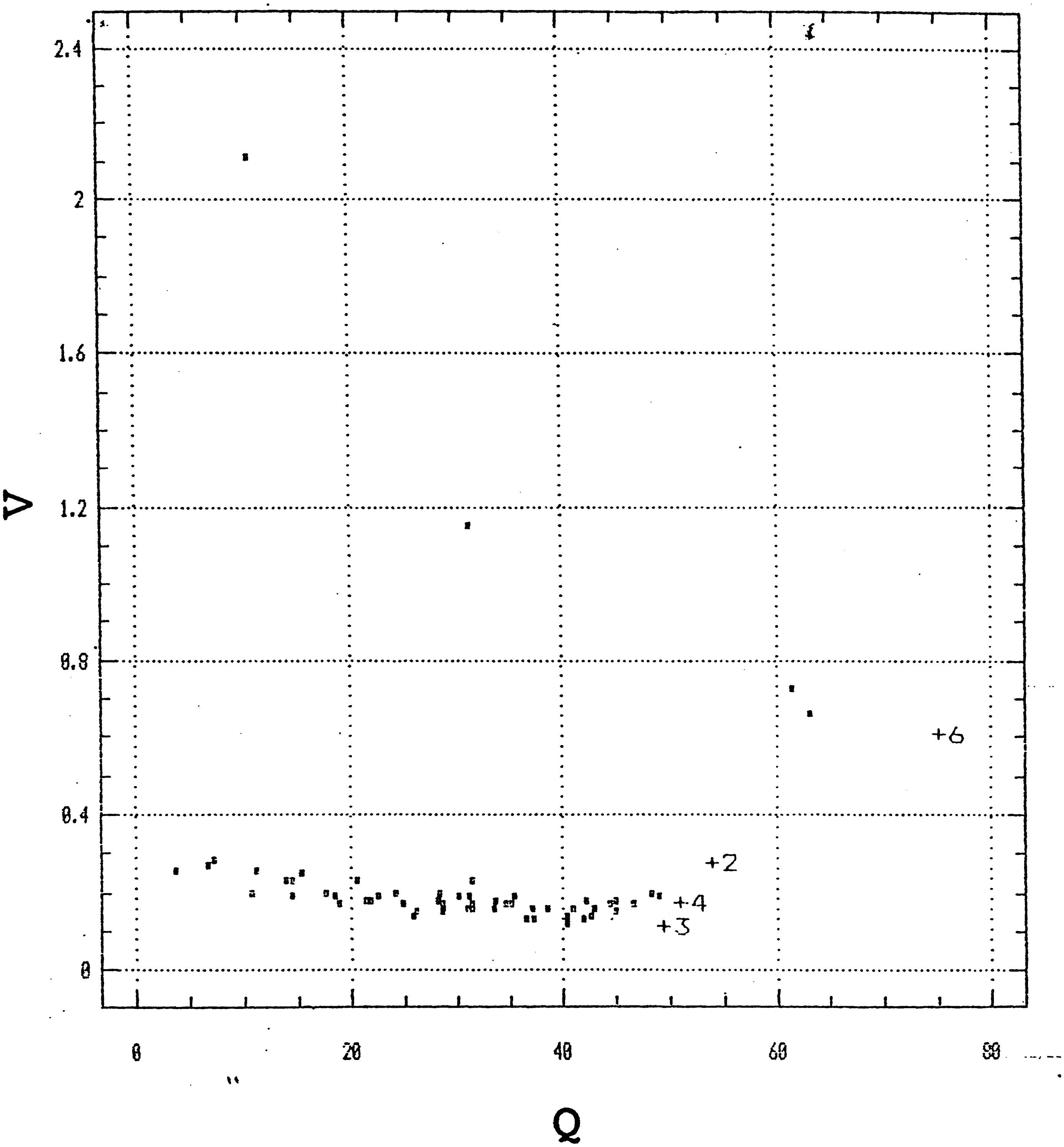


Fig 6. Viable Policies Distribution on Goals Space (Hunted Animal Average Q, Minimum Population Value M, + Paretto Frontier Policy)

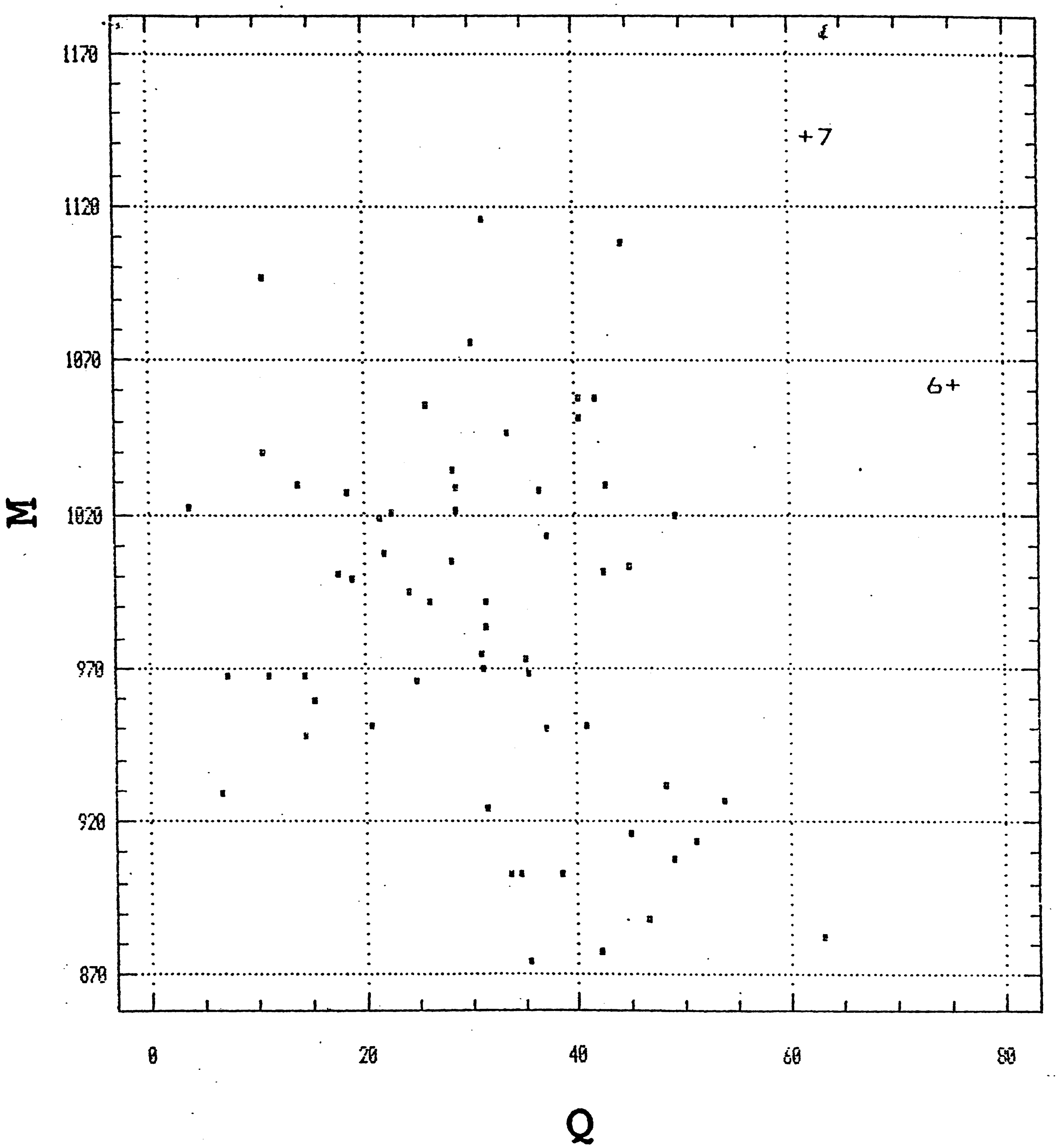


Fig 7. Viable Policies Distribution on Goals Space (Variance of Hunted Animal Average V, Minimum Population Value M, + Paretto Frontier Policy).

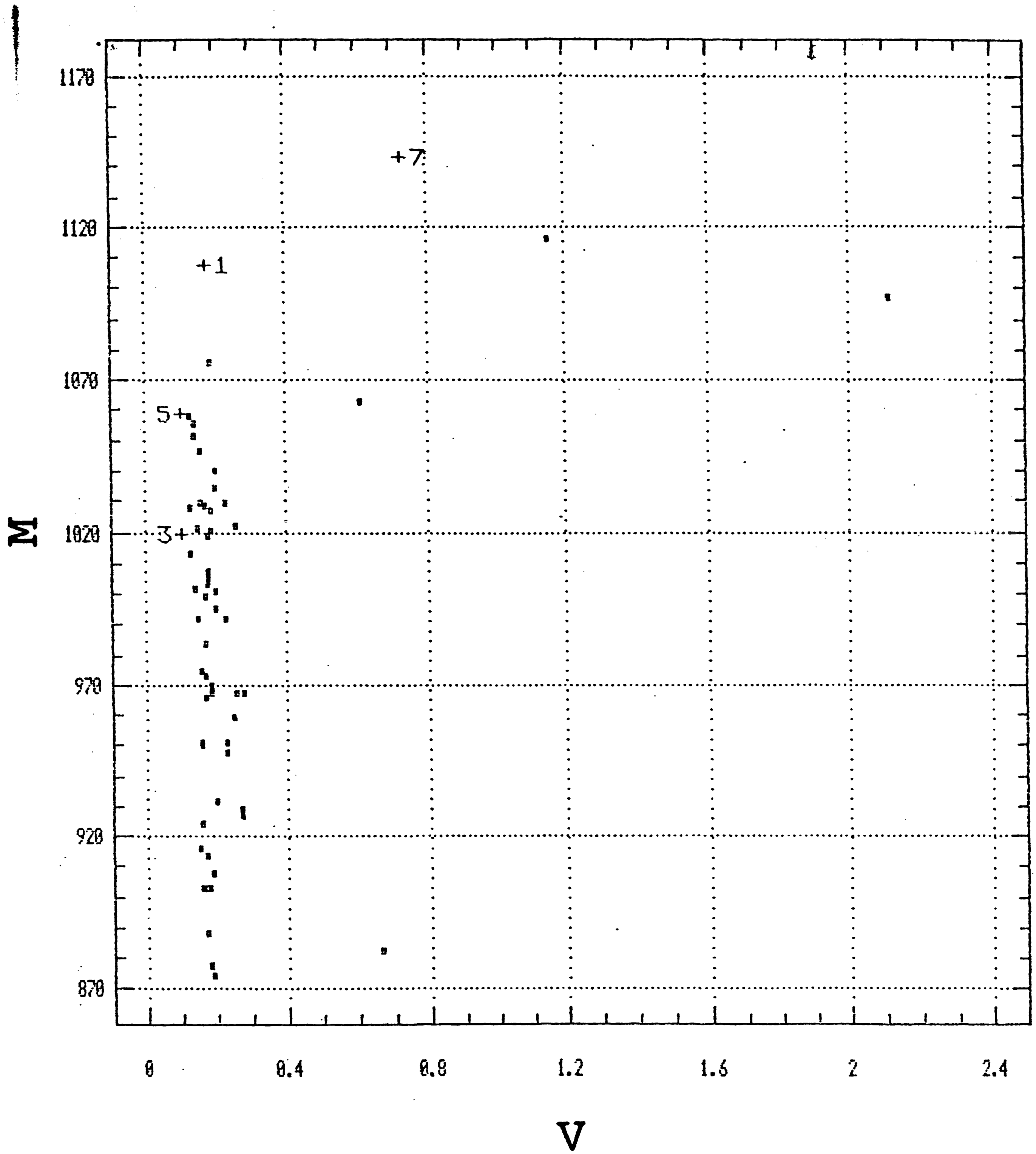


Table 4. Pareto Frontier Policies

Fixed Hunting Proportion Policies

p1	p2	p3	A	Q	V	M	
0.0	0.0	0.05	1455	30.10	0.19	800.3	1
0.0	0.0	0.075	1449	44.45	0.17	809.4	2
0.05	0.1	0.025	1336	49.35	0.12	50.0	3
0.075	0.0	0.075	1289	51.07	0.17	62.0	4
0.075	0.05	0.025	1391	40.41	0.12	805.9	5

Fixed Reproductive Stock Policies

st	A	Q	V	M	
700	1337	75.3	0.61	797.2	6
800	1454	61.4	0.73	852.1	7

p1 p2 p3 Harvested proportion of age 1, 2 and 3 , ≥ 4 year old individual respectively
st Reproductive Stock Level
A Average Population Level
Q Hunted Animal Average
V Variance of Hunted Animal Average
M Minimum Population Level

Underlined numbers are used to recognize each policy in figures 5, 6 and 7.

CONCLUSIONS

1- Delayed two year density dependence effect was detected on growth rate and mortality rate.

2- Allee effect was detecting on Kid mortality rate

3- Survival Curve was described as a Power Exponential Distribution multiplied by a Density dependence function

4- One set of optimal harvesting policies was found.